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THE EFFECT OF CLOUDINESS ON THE OXYGEN CONTENT OF WATER AND ITS SIGNIFICANCE IN CRANBERRY CULTURE

H. F. BERGMAN

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In the culture of cranberries it is often necessary to flood the bogs as a protection against frost and certain insects. The length of the flooding period may vary from a few hours to several days. To ascertain the relation between the oxygen content of waters and injuries which had occurred to the vines as a result of flooding, an investigation was begun in 1918. This work was carried on during the seasons of 1918 and 1919 in the cranberry regions of Massachusetts and Wisconsin.

One of the first things that became apparent as a result of the study of flooding water of cranberry bogs was the extent of variation of the oxygen and carbon dioxide content of water from different sources and the correlation of these variations with weather and other conditions. The oxygen and carbon dioxide content of exposed waters under certain conditions varies considerably as between day and night. The extent of this variation is affected by the amount of sunlight during the day as determined by the presence or absence of clouds. The velocity and direction of the wind and the temperature of the water also affect the gas content of flooding waters but are less important than light intensity.

The effect of cloudiness on the oxygen and carbon dioxide content of water is indirect, resulting from the action of light on submerged vegetation. When plants are submerged, oxygen and carbon dioxide during respiration or photosynthesis are absorbed from the water or given off into it in solution. Accordingly, the oxygen content of the water is increased during the day in proportion to the amount of vegetation present and to the light intensity, while the carbon dioxide content decreases under the same conditions.

The presence of oxidizable organic matter in the water or in the substratum tends to reduce the oxygen and to increase the carbon dioxide content of the water. This effect has been observed in the marshes, used by many Wisconsin cranberry growers for reservoirs, and in the water of cedar swamp reservoirs in Massachusetts. On a clear day the amount of oxygen produced by photosynthesis is much in excess of that used up in respiration or by the oxidation of organic matter. For this reason, when vegetation is present, an accumulation of oxygen occurs. In cloudy weather the accumulation is less. The oxygen content may even decline in densely cloudy weather. A diurnal variation is thus to be expected in ponds with vegetation and decaying organic matter, the amplitude of variation depending on the relative amount of vegetation and of organic matter and on the intensity of the light.

In regard to diurnal variation in the oxygen content of lake water Birge and Juday (1, p. 53) state that:

> "Some European observers have noted marked diurnal changes in the amount of dissolved oxygen in small, shallow bodies of water, especially fish ponds, and attention has been called to such changes in the upper water of Lake Mendota in September, 1908 (p. 43). In Mendota, the excess oxygen stratum comprised only the upper two or three meters which were readily disturbed by wind and by convection currents. Thus there was a pretty thorough mixture of this upper water at night so that the oxygen became uniformly disturbed in this stratum. As a consequence, there was an appreciable decrease in the quantity of oxygen in the layer having the largest excess, that is at a depth of 1.5 m., and on the succeeding day the amount of oxygen would again decrease at this depth, thus producing a diurnal variation of 1 cc. to 1.5 cc. per liter of water. But where the excess oxygen has been found in the thermocline region, no appreciable diurnal variations have been noted. That is, the difference between day and night observations did not prove to be any greater than the differences between two sets of day observations, one of which was made immediately after the other."

Birge and Juday were dealing mostly with large, deep bodies of water containing relatively little vegetation and with bottoms free of organic deposits. Under such conditions the oxygen content of the water depends chiefly upon the temperature of the water. According to Pettersson and Sonden (5, p. 1443), a liter of water at 0° C. and 760 mm. pressure is capable of absorbing from the atmosphere 10.01 cc. of oxygen. Roscoe and Lunt (6) state that under these conditions water requires only 9.7 cc. of oxygen for saturation. The oxygen capacity decreases with a rise of temperature. Thus Roscoe and Lunt give 6.28 cc. as the amount of oxygen required for saturation of water at 20° C. and 5.76 cc. at 25° under 760 mm. pressure.

The latitude of variation in the carbon dioxide and oxygen content of waters in the cranberry region of Massachusetts may be shown by a few typical examples presented in table 1.

Spectacle Pond shows the least variation in carbon dioxide and oxygen content from day to day and between clear and cloudy weather. The carbon dioxide content ranges from 0.1 to 0.7 cc. per liter and the oxygen content from 5.4 to 6.5 cc. per liter. In Cedar Pond the range is greater, the carbon dioxide content varying from 0.4 to 2.8 cc. per liter depending on weather conditions and place of sampling. The oxygen content of Cedar Pond water varies from 4.8 to 6.0 cc. per liter. The greatest variation occurs in the water of the State Bog ditch, the carbon dioxide content ranging from 2.0 to 10.1 cc. per liter. The oxygen content similarly has a wide range, from 1.8 to 5.0 cc. per liter. The same relation obtained in 1919, as shown in figure 1.

Although there is some variation in temperature on the different days and hours at which these readings were made, this variation is not sufficient to account for the difference in gas content. These samples, with the exception of those taken from Spectacle Pond July 30 and from the State Bog August 10, were all taken in clear weather in shallow water near shore. The bottom of Spectacle Pond is clean white sand and the water very clear. In Cedar Pond the water is clear but the bottom is muck, consisting of vegetable matter most of which is well decomposed. The water in the ditches of the State Bog is discolored, of a very dilute coffee color as viewed by transmitted light, and the bottom is muck as in Cedar Pond. Spectacle Pond, moreover, has very little vegetation, which accounts for the almost constant oxygen and carbon dioxide content from day to day or between day and night periods. On the other hand, Cedar Pond is well filled with water lilies and other vegetation which modifies the oxygen and carbon dioxide content of the water materially through respiratory and photosynthetic activities. In the State Bog ditches a more or less abundant growth of algae is found which brings about the same result. Accordingly, both in Cedar Pond and in the ditches of the State Bog a wide variation in carbon dioxide and oxygen content of the water is observed between day and night or between a clear and a cloudy day. Where the vegetation is denser the variation is more pronounced.

TABLE 1. *Variation in oxygen and carbon dioxide content of waters at East Wareham, Massachusetts*

Source	Date, 1918	Weather	Hour	Temp. C	Carbon Dioxide Cc. per Liter	Oxygen Cc. per Liter
Ditch, State Bog	July 3	Clear	9:00 A.M.	24°	10.1	0.9
" " "	" "	"	11:00 A.M.	25	3.6	2.5
" " "			3:00 P.M.	26.5	2.0	4.9
" " "	29		9:00 A.M.	25	6.4	2.4
" " "			11:00 A.M.	27	5.2	3.6
" " "			2:30 P.M.	29	4.5	5.0
" " "	" "	"	4:00 P.M.	29.5	4.0	5.1
" " "	Aug. 10	Cloudy	11:00 A.M.	20	5.1	1.8
" " "	" "	"	1:45 P.M.	20.5	3.9	3.6
Spectacle Pond	July 15	Clear	9:00 A.M.	21°	0.7	6.1
" "	" "	"	11:00 A.M.	22	0.7	6.1
" "	" "	"	3:00 P.M.	24	0.4	6.1
" "	" 17	"	10:30 A.M.	24	0.3	6.1
" "	" "	"	3:00 P.M.	26	0.2	6.5
" "	" 30	Cloudy	9:00 A.M.	25	0.3	5.4
" "	" "	"	11:00 A.M.	26	0.2	5.4
' "	' "					
" "	" "	"	2:30 P.M.	26	0.1	5.7
" "	" "	"	4:00 P.M.	26	0.1	5.9
Cedar Pond	Aug. 1	Clear	9:30 A.M.	22	0.5	4.5
" "	" "	"	" " "	22	0.5	4.9
" "	" "	"	3:00 P.M.	29	0.4	5.1
" "	" "	"	" " "	29	0.45	5.5
" " (east end)	" 6	"	9:30 A.M.	22	2.8	3.3
" "	" "	"	4:00 P.M.	27	1.1	4.8

The carbon dioxide content of the water in Cedar Pond and in the ditches of the State Bog is much higher than that of the water in Spectacle Pond. This is due to the large amount of decaying organic matter which is constantly giving off carbon dioxide. The carbon dioxide content of the water of Cedar Pond and the State Bog ditches is higher and the oxygen content lower in the morning for three reasons: First, because photosynthesis does not take place during the night and carbon dioxide is not withdrawn by the plants. Second, respiration is going on, as a result of which carbon dioxide is given off and oxygen taken up. Third, the organic matter on the bottom is slowly taking up oxygen and liberating carbon dioxide. This applies also in cloudy weather.

Even after these facts had been ascertained, their significance as a factor in cranberry culture was not fully appreciated until the spring of 1919. Attention was then called forcibly to the importance of weather conditions in relation to the oxygen content of flooding water through the difficulty which many of the growers experienced in injury to the buds and new shoots of cranberry plants, resulting from the flooding of bogs during a period of cloudy weather. Although data had already been obtained which would apparently account for injury under such circumstances, it seemed advisable to make further investigations upon this point.

Dr. H. J. Franklin, of the Massachusetts State Cranberry Station at East Wareham, had planned some experiments with cranberries to determine whether or not reduction of light could cause injury to cranberry blossoms or tips. Four pieces of cranberry sod were dug up and placed in galvanized iron tubs. Two of these tubs were filled with ditch water and set in the main ditch of the State Bog so that the edge of the tub was an inch or more above the surface of the water in the ditch. This prevented the entrance of any water from the outside. One of the tubs was covered with pieces of corrugated metal roofing to exclude light, while the other was left exposed. Two other tubs containing pieces of cranberry sod were similarly placed in Spectacle Pond.

The experiment began in the late afternoon of June 28, 1919. Analyses for the oxygen content of the water in each of the four tubs, in the main ditch, and in Spectacle Pond were made at the beginning of the experiment. Other analyses were made at sun-down, at 10:00 to 11:00 p.m., before sunrise the next morning, and two or three times during the day. This general procedure was followed throughout the experiment although samples were not taken as frequently after the second day. The experiment extended through four days for the vines in Spectacle Pond. The vines in the ditch were taken out after three days. The results of the analyses for oxygen are presented in figures 1, 2, and 3. The determinations of oxygen content were made by the Winkler (7, p. 2843) method.

The results were strikingly clear. The vines in the shaded tub in the ditch had all, or nearly all, of the blossoms and many of the growing tips either killed or injured. On the vines in the unshaded tub in the ditch almost no injury was evident. In the set of tubs in Spectacle Pond the same thing occurred. The plants in the shaded tub were obviously seriously injured while the vines in the unshaded tub escaped with little or no apparent injury. It will be observed on consulting the graphs that the oxygen content of the water in the shaded tubs both in Spectacle Pond and in the ditch dropped very rapidly after the experiment was begun and remained at a very low and essentially constant level throughout the course of the experiment. That the oxygen content did not reach a point of absolute deficiency at any time is probably to be accounted for by the fact that oxygen is taken up slowly from the air.

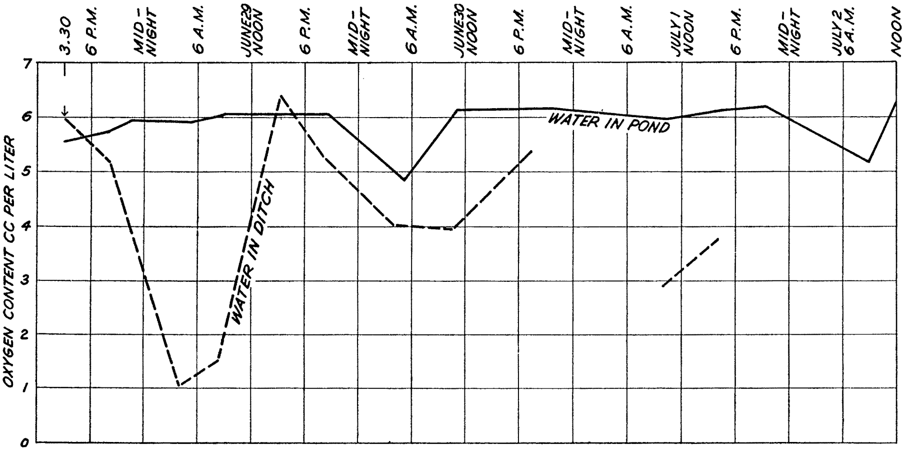

FIG. 1. Oxygen content of water from Spectacle Pond and the State Bog ditch, East Wareham, Massachusetts, 1919.

The oxygen content of the unshaded tubs, both in Spectacle Pond and in the ditch, showed considerable variation between the day and night periods (figs. 2 and 3). The variation between day and night was very uniform throughout the experiment, the oxygen content of water in the unshaded tub in Spectacle Pond running slightly higher than in the unshaded tub in the ditch. The oxygen content of the water in Spectacle Pond showed very little variation from day to day or between day and night (figs. 1 and 2) at any time during the experiment. Only on two occasions was a considerable change in the oxygen content of the pond water observed. One of these was at five o'clock on the morning of June 30, the other at nine o'clock on July 2. The decrease in the oxygen content of the water at these times is due to the fact that the water samples were taken too close to the outlet ditch from the State Bog, so that the sample contained a considerable portion of bog water mixed with the pond water. As the bog water contains considerably less oxygen, the result of mixing it with the pond water is to reduce the oxygen content of the latter.

The ditch water also showed a wide variation between day and night in this experiment. This is due to the presence of algae in the water, since these plants during the day were actively giving off oxygen and were using it up during the night in respiration. The lack of vegetation in Spectacle Pond accounts for the uniformity of the oxygen content as between day and night, the slight changes occurring being due mostly to the difference in temperature.

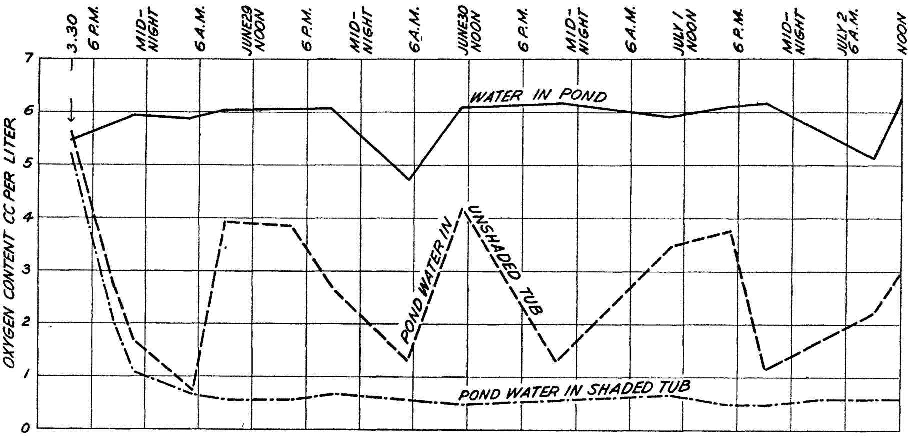

FIG. 2. Oxygen content of water from Spectacle Pond, East Wareham, Massachusetts, and of water from Spectacle Pond held in tubs under experimental conditions, 1919.

From this experiment it is evident that injury occurred only to the plants in the shaded tubs, the water of which shows a great reduction below the oxygen content of either pond or ditch water (figs. 2 and 3). As the oxygen content was the only factor which was changed extensively throughout the experiment, the injury must be attributed to the lack of oxygen.

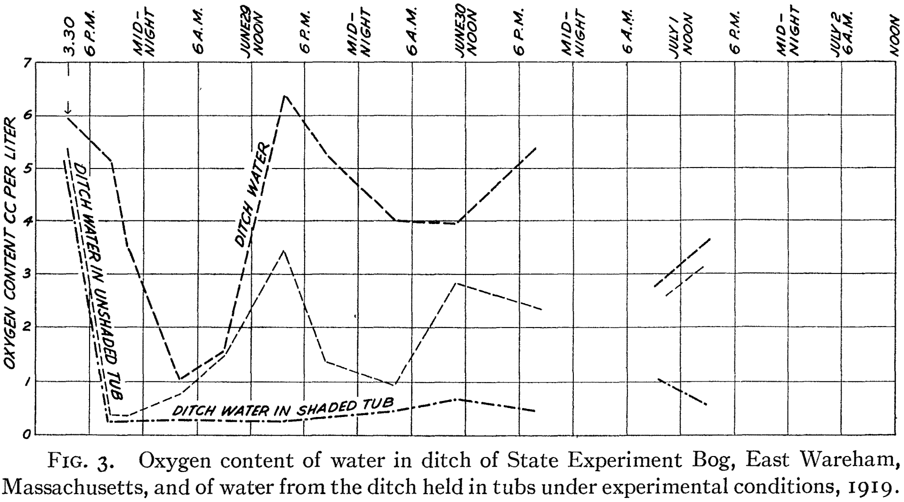

FIG. 3. Oxygen content of water in ditch of State Experiment Bog, East Wareham, Massachusetts, and of water from the ditch held in tubs under experimental conditions, 1919.

Very little difference was noted as to degree of injury between shaded plants in ditch water and shaded plants in pond water. This indicates that nothing in the quality of the water aside from lack of oxygen caused the injury. The plants that were submerged but not shaded suffered little or no injury. Analyses of the water show that in these tubs the oxygen content decreased only during the night and did not remain long at a low level. The shading during the day prevented the accumulation of oxygen which would have carried the plants through a considerable part of the night. Cloudiness would have the same effect, the effect being more pronounced with greater reductions of light.

In this connection, attention may be called to the rate of respiration of the flowers and of the young and old shoots of cranberry plants as measured by the rate of production of carbon dioxide per unit of weight material. The experiments were made with Early Blacks. A weighed amount of flowers, growing tips, and old shoots was placed in closed receptacles of known volume. Determinations of carbon dioxide were made at definite intervals after the experiment was started. Analyses were made with an Allen-Moyer Orsatt apparatus. The readings were corrected to show the volume of dry gas at 0° C. and at a pressure of 760 mm. The results are given in table 2.

TABLE 2. *A comparison of the carbon dioxide production of flowers, growing tips, and old shoots of cranberries*

Date	Material	Weight in Grams	Volume in Cc.	Duration of Experiment	Temp. C.	Carbon Dioxide		
						% Observed	Cc. per Hour	Cc. per Hour per 100 G,
July 7	Flowers	11.0	25	2 h. 15 m.	22°	0.4	4.2	38.6
" "	Growing tips	19.0	35	2 h. 20 m.	"	0.7	7.1	37.4
" "	Old shoots	36.5	54	2 h. 15 m.	"	0.5	5.2	14.3
" 8	Flowers	11.0	25	15 h. 10 m.	"	2.0	2.5	22.0
" "	Growing tips	19.0	35	"	"	3.0	3.7	19.3
" "	Old shoots	36.5	54	"	"	2.6	3.3	6.1
" 14	Flowers	13.7	26	1 hour	25.5	0.45	10.5	76.5
" "	Growing tips	25.9	39	"	"	0.5	11.6	46.2
" "	Old shoots	40.5	57	"	"	0.5	11.5	28.3
" 14	Flowers	13.7	26	2 hours	27.5	0.5	11.5	42.0
" "	Growing tips	25.0	39	"	27.5	1.0	22.9	45.8
" "	Old shoots	40.5	57	"	"	0.6	13.7	16.9
" 14	Flowers	13.7	26	"	28.0	0.5	11.5	41.8
" "	Growing tips	25.0	39	"	"	0.9	20.6	41.0
" "	Old shoots	40.5	57	"	"	0.5	11.5	14.0

From the results of these experiments it is evident that under the same temperature conditions the flowers and growing tips show a much higher rate of production of carbon dioxide than do the old shoots. Nicolas (4, p. 109), in some twenty plants studied, found respiration more rapid and the respiratory quotient higher in young leaves than in those fully matured. Most of the experiments indicate (see table 2) that the flowers produce carbon dioxide at a slightly higher rate than the growing tips, although in the second trial on July 14 this is not true. In these experiments the flowers and growing tips produced carbon dioxide two to three times as fast as did the old shoots. Maige (3, p. 1) has shown in experiments with a large number of plants that the intensity of respiration of floral organs is greater than that of leaves. A more rapid rate of respiration, however, means a greater oxygen requirement. This accounts for the injury to the flowers and growing tips resulting from prolonged submergence in water deficient in oxygen.

From the data submitted it is evident that injury is most apt to occur to a bog by flooding during a period of cloudy weather. Naturally the injury is apt to be greater the longer the period of time during which the water is held on the vines, and especially if cloudiness prevails throughout the period. The degree of injury is probably not directly proportional to the reduction in light intensity, for, as Brown and Heise (2, p. 85) point out, the published works on carbon dioxide assimilation "indicate a progressively smaller augmentation of the rate of assimilation for each increase in light intensity." A certain, as yet unknown, reduction in light intensity is necessary to bring about a balance between the photosynthetic and the respiratory activity. After this point has been reached, accepting the conclusions of Brown and Heise (2, p. 94), each decrement in light intensity should have a progressively greater injurious effect.

A number of other factors which may affect the result are operative. Much depends upon the character of the water as it is placed on the bog. Clear pond or river water has a higher initial oxygen content, so that the oxygen is not depleted as rapidly as from a water supply initially deficient in oxygen. Where water from a cedar swamp, or other reservoir having a great deal of organic matter on the bottom, is used, the initial oxygen content may be very low. This, as indicated elsewhere, is due to the fact that organic matter absorbs oxygen and gives off carbon dioxide. In cloudy weather the initial oxygen content of water from a swamp reservoir would be considerably lower than in clear weather. All other factors remaining the same, greater injury would result during a period of warm weather than of cool, due to the increase in the rate of respiration with a rise of temperature. On the other hand, the ability of the water to absorb oxygen diminishes with an increase of temperature.

In conclusion it may be pointed out that the matter of oxygen content as affected by light intensity and other factors is of great importance in combating insect pests by flooding. A combination of factors producing a low oxygen content in the flooding water at a time when the insect larvae are active is most desirable. Such conditions would, however, be highly detrimental to the cranberries. It would be necessary, therefore, to consider the state of activity of the cranberries and of the insect larvae, and, if possible, to adjust the length of the flooding period so that the larvae would be killed without injury, or at least without extensive injury, to the vines. A careful study of these problems is highly desirable.

SUMMARY

In a study of flooding water of cranberry bogs of Massachusetts and Wisconsin a variation in oxygen and carbon dioxide content of the water was observed.

The effect of cloudiness on the oxygen and carbon dioxide content of water is indirect, resulting from the action of light on submerged vegetation.

The variation in oxygen and carbon dioxide content of flooding water in the cranberry region of Cape Cod, Massachusetts, as affected by light intensity, organic matter, and abundance of vegetation, is shown.

An experiment is described showing the effect of shading submerged cranberry vines. The resulting injury is due to reduction of oxygen content of the water. No essential difference was observed between the amount of injury to shaded vines in pond water and that to shaded vines in bog ditch water.

The flowers and growing tips of shoots, which were the parts most seriously affected, have a higher respiratory rate than old shoots, as shown by experimental results. This accounts for their greater injury by submergence in water deficient in oxygen.

Injury is most apt to occur to a bog by flooding during cloudy weather.

BUREAU OF PLANT INDUSTRY,
WASHINGTON, D. C.

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